"Near Field" Communication

The "Near Field" low frequency communication applications have been neglected for quite some time. However, suitable applications still exist and should be more closely examined.

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Despite the fact that "microwaves" became quite a buzzword in the last few decades, there are still some applications for the lowly low frequencies. In the thirties, high power low frequency broadcasting stations were quite de rigueur practically everywhere but in the United States. I remember, as a child, putting together my first crystal set to listen to Warsaw I at about 2000 kHz. Thanks to the high power output and a good ground wave, reliable reception could be had with the simplest equipment. In those days all you needed was a crystal (not a JAN1NTX diode, but a hunk of galena with a "sensitive spot"), some wire, a cold pipe for ground and the power line for an antenna (if you were very careful - I almost burned the house down when my "antenna" shorted to my "ground") and you were in business. During World War II, when amateur transmissions were restricted, low frequencies enjoyed a short revival in the United States. Some hams, not willing to give up their hobby, switched to carrier current as means of communicating. This meant operation below 100 kHz, using the power lines as transmission lines. Theoretically, the radiation was supposed to be negligible, but it was possible to "jump" from one power line to another. This was handy in places like Boston, where some of the power was AC and some DC therefore line jumping was necessary to obtain reasonable distances.

Long range (high power) applications for low frequencies always existed, such as: communicating with submarines at sea, navigation (Omega, Loran-C, Decca), and timing (WWVB and US Navy standard frequency and time stations such as NAA, NSS NLK).

For a while things were quiet on the low frequency front, until garage door openers first became popular in the late forties. To provide "license-less" operation (it is doubtful if the average motorist could pass any kind of FCC exam), a very low power operation was required by the FCC. This is where "near field" operation comes in [Reference 1]. To meet the low maximum allowable field strength permitted, the fact that the field varies as the inverse cube of the antenna separation for distances considerably less than a wavelength, was utilized. At distances over one wavelength, the usual inverse law applies. Thus, using very low frequencies (long wavelengths), a usable signal level could be obtained while still satisfying the FCC requirements.

It may be desirable, at this point, to define what is meant by "near field." An RF current in a transmitter loop antenna produces an oscillatory magnetic field. This field, in turn, induces a proportional current in a receiver loop antenna placed in it. Thus, the transmitter loop — receiver loop system can be thought of as a very loosely coupled ("leaky") transformer (see Figure1).

The formula for mutual inductance of two parallel coils, as shown in Figure 1, is [Reference 2]:

$$M = \frac{\mu.\pi}{16} \sqrt{r_R r_T} \left[\frac{4 r_R r_T}{(r_R + r_T)^2 + d^2} \right] \quad (1)$$

which, for $r_R + r_T << d$ (the usual case), can be simplified to:

$$M = 0.2\pi^2 \frac{r_T^2 r_R^2}{d^3} \quad (2)$$

Using the formula for induced voltage:

$$e = -j\omega M i \quad (3)$$

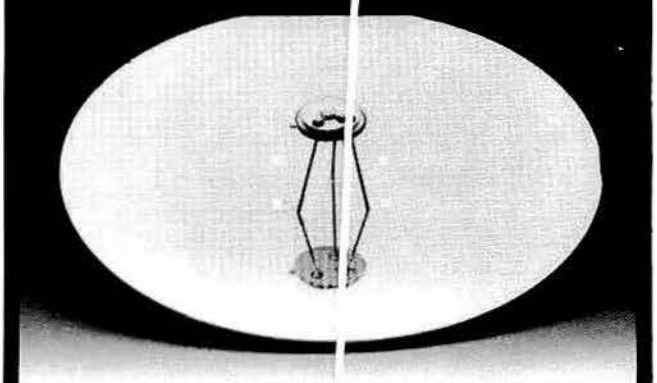
and taking into account the fact that multiturn coils are used, the overall system formula for induced voltage in the receiver loop antenna becomes:

$$e_R = 0.4\pi^3 \frac{r_T^2 r_R^2 n_T n_R}{d^3} f i_T \quad (4)$$

Basically, the same results can be obtained using Henney's formula for radial near field [Reference 3]:

$$e_n = \frac{18.85\, n_T r_T^2}{d^3} i_T \times 10^7 \quad (5)$$

A quartz resonator for UHF oscillators has surfaced...



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and Terman's for induced receiver loop voltage [Reference 4]:

$$e_R = 2\pi e N \frac{A}{\lambda} \quad \text{where e can be } e_n \text{ or } e_i. \tag{6}$$

The induced receiver antenna voltage thus becomes:

$$e_R = 3.9585\pi \frac{r_T^2 r_R^2 n_T n_R}{d^3} f i_T \tag{7}$$

For comparison, the "far" field transfer function was derived:

$$e_R = 8.89\pi^5 \frac{r_T^2 r_R^2 n_T n_R}{d} f^3 i_T \times 10^{-18} \tag{8}$$

using [Reference 5]:

$$e_i = \frac{120\pi^3 n_T r_T^2}{d\lambda^2} i_T \tag{9}$$

and Equation (6).

The inverse and inverse cube relationships are clearly visible in Equations (8) and (7). Figure 2 shows them for normalized conditions ($r_R = r_T = n_R = n_T = i_T = 1$) for an RF frequency of 100 kHz. It can be seen that at a distance of just under ¼ wavelength the performance of the two approaches is equal. At shorter distances, the "near field" is clearly superior. At longer distances, the more common "far field" performance is better.

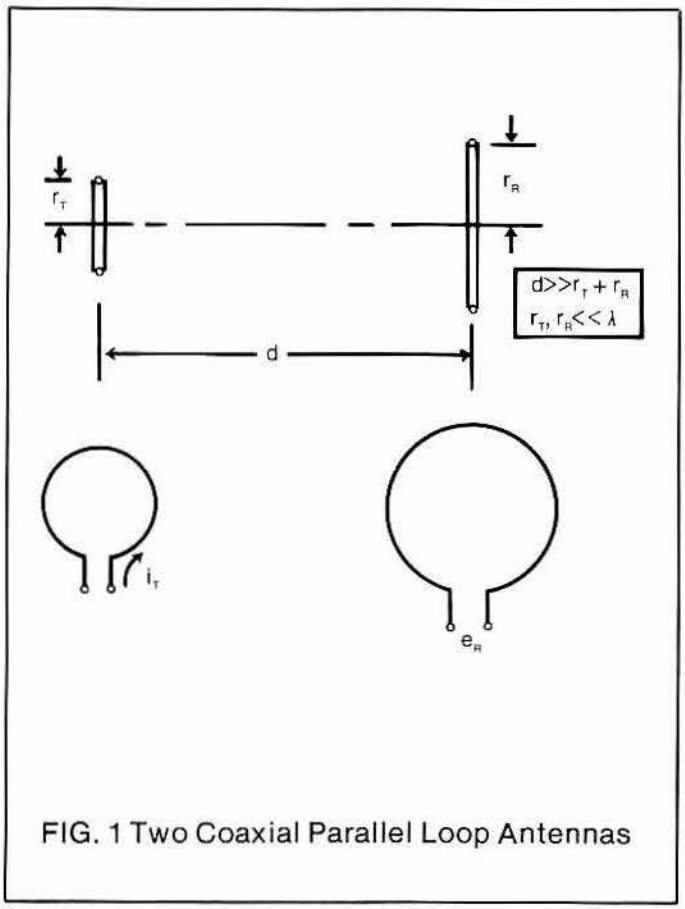

FIG. 1 Two Coaxial Parallel Loop Antennas

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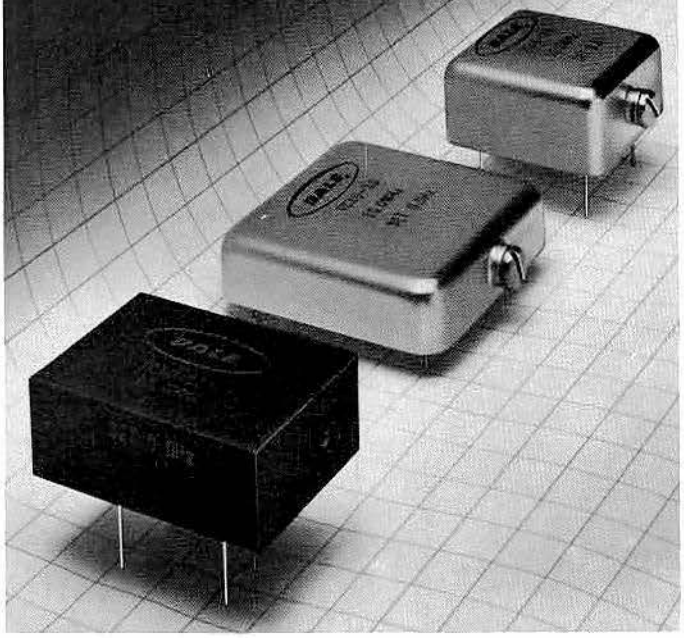

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Table 1
Definitions

f = frequency, hertz
d = loop antenna separation, meters
n_T = number of turns in transmitter loop antenna
n_R = number of turns in receiver loop antenna
r_T = radius of transmitter and antenna loop, meters
r_R = radius of receiver antenna loop, meters
i_T = transmitter RF loop current, amperes
e_n = near-field strength, microvolts per meter
e_f = far-field strength, microvolts per meter
e_R = voltage induced in receiver loop antenna, microvolts
M = mutual inductance, microhenries
μ_o = permeability of free space, $4\pi \times 10^{-7}$ henries per meter
λ = wavelength, meters
A = loop antenna area, square meters

Table 2
FCC Regulations - Part 15

Maximum allowable field strength for nonlicensed operation:

Frequency - kHz	Distance - meters	Field Strength
10-490	300	2400/frequency
510-1600	30	24,000/frequency
Frequency - MHz		
70-130	30	50
130-174	30	50-150 (linear interpolation)
174	30	150
260-470	30	150-500 (linear interpolation)
470 and above	30	500

There are many applications where the "near field" approach provides important advantages. They are basically low power short range systems which can be divided into two main categories:

-systems which cannot exceed a certain field strength at a specified distance, and

-systems where partial security of transmission is desired.

A typical example of the first is the FCC low power requirement mentioned before in connection with the garage openers. To operate without a license, the low power FCC requirements have to be satisfied, as shown in Table 2. Figure 3 shows a comparison of operation at two frequencies: 100 kHz and 200 MHz. The maximum FCC allowable signal strengths are indicated. At distances of over about 400 meters the 200 MHz system will provide higher field strength, but at very short distances over 40 dB higher field strengths are provided using the low frequency approach. A free bonus is the reduced interference with other receivers located nearby, since the inverse cube relation applies to a distance of about 670 meters.

In addition to the above advantages, the lower frequency usually provides better propagation characteristics. It penetrates solid objects better and does not exhibit the usual nulls encountered in VHF operation.

The other application is in partially secure (or non-interfering) short distance communication systems. Let's assume

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that a system is needed having a minimum signal-to-noise ratio of 40 dB at transmitter/receiver separation of 100 meters. The intelligence bandwidth is 10 kHz. Two systems will be compared: one at 400 MHz and one at 50 kHz. Assuming a receiver noise level equivalent to a field strength of one microvolt per meter [Reference 6], a field strength of 100 microvolts per meter at 100 meters is needed, as shown in Figure 4. At a distance of 10,000 meters the system will have a 0 dB S/N.

On the other hand, the 50 kHz system, while requiring considerably higher field strength to provide the required S/N, will be lost in the atmospheric noise [Reference 6] (S/N of 0 dB) at a distance of only about 460 meters, as shown in Figure 5. Thus, security is considerably enhanced compared to the VHF system.

The necessity of using loop antennas is sometimes considered a disadvantage of the low frequency, near field systems. While modern loop design data is somewhat scarce, it is possible to design efficient structures [Reference 7] with minimal effort.

The above analysis is not meant to be all-inclusive, but it shows that the long neglected low frequencies still have some modern applications. Each individual short-range system requirements have to be considered before a final decision can be made, but in many cases the low frequency approach may have considerable advantages. In addition, after working at VHF and UHF it is quite a revelation to find out that capacitors really behave like the book says and an inductor is + j and not -j.

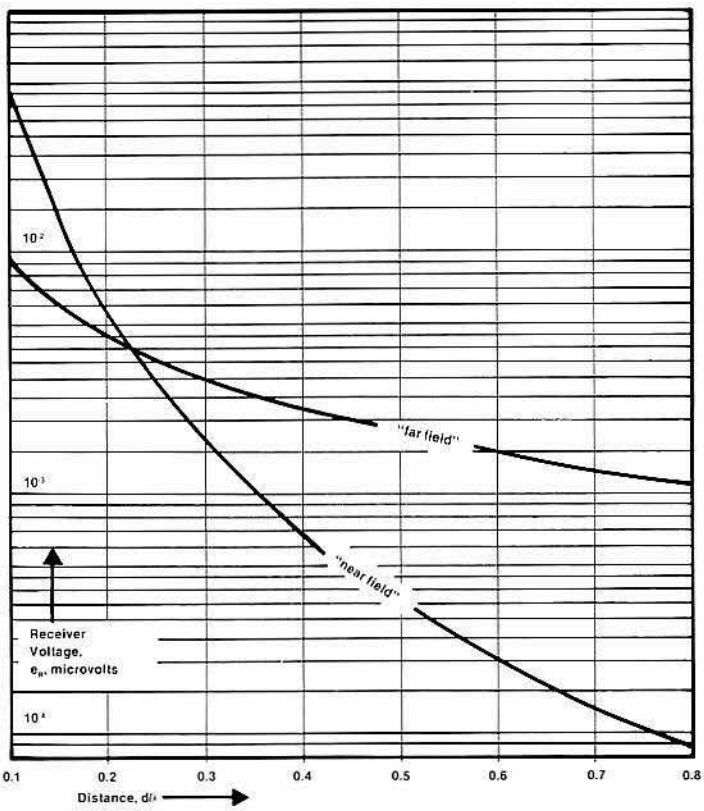

FIG. 2 Induced Receiver Voltage, e_R (Normalized)

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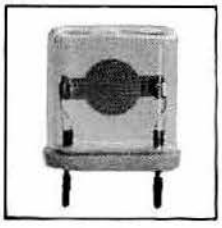

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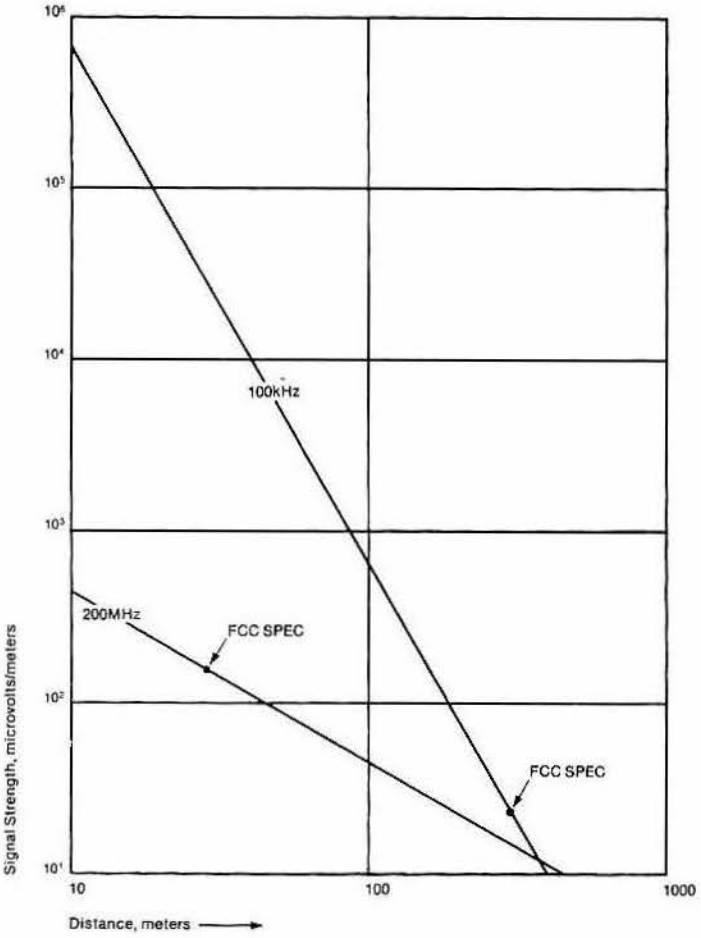

Fig. 3 Operation Under FCC "Low Power" Rules.

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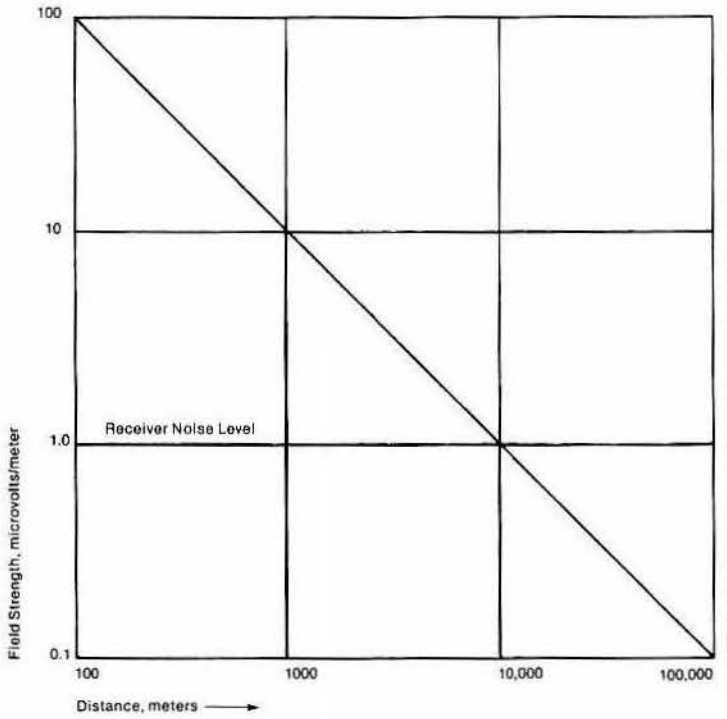


Fig. 4 Signal Levels Using 400 MHz.

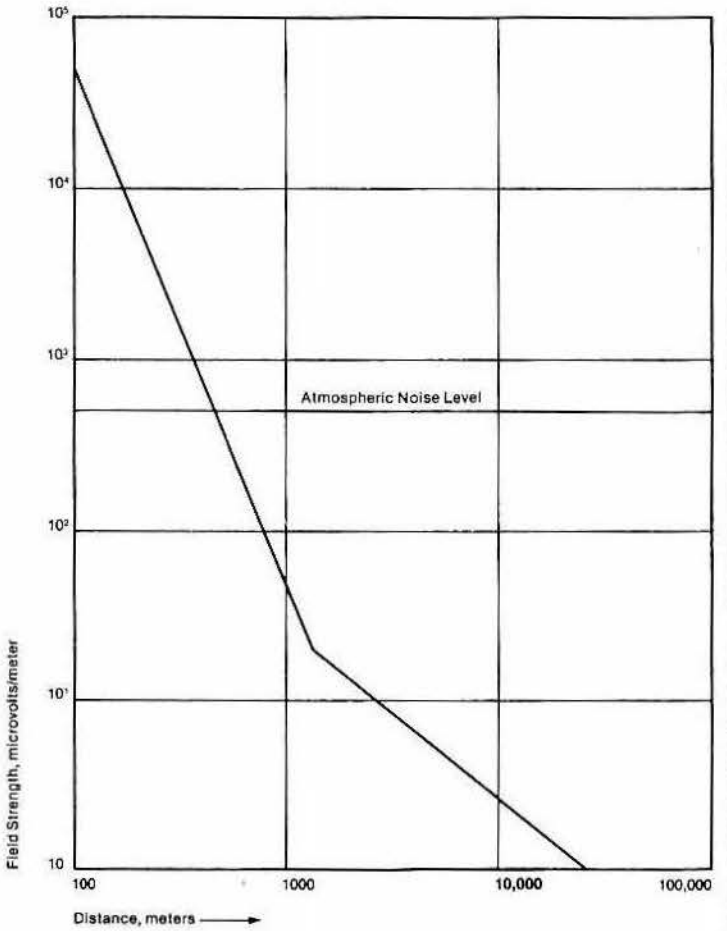
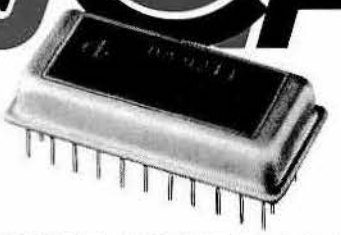


Fig. 5 Signal Levels Using 50 kHz.

VCA



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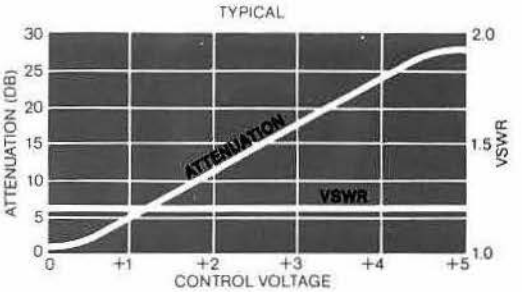

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